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The 2010 AOP Workshop Summary Report

Stanford B. Hooker, John H. Morrow, James W. Brown, and Elaine R. Firestone

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Abstract

The rationale behind the current workshop, which was hosted by Biospherical Instruments Inc. (BSI), was to update the community and get community input with respect to the following: topics not addressed during the first workshop, specifically the processing of above-water apparent optical property (AOP) data within the Processing of Radiometric Observations of Seawater using Information Technologies (PROSIT) architecture; PROSIT data processing issues that have developed or tasks that have been completed, since the first workshop; and NASA instrumentation developments, both above- and in-water, that are relevant to both workshops and next-generation mission planning. The workshop emphasized presentations on new AOP instrumentation, desired and required features for processing above-water measurements of the AOPs of seawater, working group discussions, and a community update for the in-water data processing already present in PROSIT. The six working groups were organized as follows: a) data ingest and data products; b) required and desired features for optically shallow and optically deep waters; c) contamination rejection (clouds), corrections, and data filtering; d) sun photometry and polarimetry; e) instrumentation networks; and f) hyperspectral versus fixed-wavelength sensors. The instrumentation networks working group was intended to provide more detailed information about desired and required features of autonomous sampling systems. Plenary discussions produced a number of recommendations for evolving and documenting PROSIT.

1. INTRODUCTION

The processing of data collected to measure the apparent optical properties (AOPs) of seawater is a fundamental part of the calibration and validation of ocean color satellite missions, because the data products are directly comparable to the spaceborne measurement: the spectral radiance emerging from the sea surface or the so-called water-leaving radiance, $L_W(\lambda)$, where λ denotes wavelength. The artificial variance imparted by processor-to-processor differences in estimating $L_W(\lambda)$ frequently equals or exceeds the total uncertainty permitted in calibration and validation field activities (Hooker et al. 2001), which is no more than a few percent (currently about 3.5%). The principal objective of the 2009 workshop (Wright and Hooker 2009†) was to specify the desired and required features of a community-maintained, open-source, Web-based interface for the Processing of Radiometric Observations of Seawater using Information Technologies (PROSIT‡).

Much of the recommended capabilities for a large variety of fixed-wavelength instrument systems were incorporated into PROSIT (Hooker and Brown 2011). The initial *beta* version of PROSIT was produced in 2009, and initial testing was completed in early 2010. The first operational version was tested in the middle of 2010 and up until the second workshop was convened 8–10 December in San Diego (California). The agenda was initially established to accomplish the same thing for above-water AOP data that the first workshop did for in-water AOP data (Fig. 1). Because the in-water processing capability was rather mature, time was also reserved for demonstrating how in-water AOP processing is accomplished using PROSIT. The latter component included time to train alongside the principal PROSIT programmer. The training opportunity included extra time before the meeting for several scientists who requested it.

Much of AOP data processing is inexorably tied to the data acquisition activity, so time was also reserved for new technology presentations associated with the above-water Optical Sensors for Planetary Radiant Energy (OSPREy), and in-water Compact-Optical Profiling System (C-OPS) instruments. The presentations showed how these two technologies are positioned to deal with the advanced planning that is occurring for the Aerosol-Cloud-Ecosystems (ACE) mission and the Pre-Aerosol, Clouds, and Ocean Ecosystem (PACE) mission that was recently announced. Many of the scientists in attendance (Table 1) have already started using some of the new instrumentation in their research work, so time before, during, and after the workshop was made available for discussions specifically tailored to the science objectives being pursued.

The rationale behind the current workshop, which was hosted by Biospherical Instruments Inc. (BSI), was to update the community and get community input with respect to the following:

1. Topics not addressed during the first workshop, specifically the processing of above-water AOP data within the PROSIT architecture;
2. PROSIT data processing issues that have developed or tasks that have been completed since the first workshop; and

† The cited meeting summary plus the workshop agenda, list of attendees, and all of the talks that were presented by the participants are available on the Web at the following Web site: `http://oceancolor.gsfc.nasa.gov/DOCS/` by going to the Meetings and Workshops heading and selecting "CVO AOP Workshop—January 2009."

‡ Literally translated from Latin as "May it benefit."

Time	8 December (Wed)	9 December (Thu)	10 December (Fri)
0830	*Welcome (S. Hooker)*	*Workshop Agenda (S. Hooker)*	*Workshop Agenda (S. Hooker)*
0840	Workshop Agenda (S. Hooker)	PI Presentation (D. Stramski)	PROSIT In-Water AOPs Overview (S. Hooker)
0850	Workshop Overview (S. Hooker)		
0900		PI Presentation (S. Ahmed)	
0910	OSPREy Overview (S. Hooker)		PROSIT In-Water AOPs Demonstration (S. Hooker and J. Brown)
0920		PI Presentation (K. Ruddick)	
0930	Introduction to Microradiometers (R. Booth)		
0940		Working Groups (S. Hooker)	
0950	OSPREy Field Radiometers (J. Morrow)		
1000		Above-Water AOPs Working Groups (A, B, and C)	
1010	PI Presentation (S. Thomalla)		
1020			
1030	*Break*	*Break*	*Break*
1100	BSI Calibration Facility Upgrades for OSPREy (R. Booth)	Above-Water AOPs Working Groups (A, B, and C)	PROSIT In-Water AOPs Discussion (S. Hooker)
1110			
1120			
1130	OSPREy Transfer Radiometers (G. Bernhard)	Above-Water AOPs Working Groups (D, E, and F)	
1140			
1150			
1200	OSPREy Data Processing (G. Bernhard)		Posters, Instrument Displays, and Questions and Answers
1210			
1220			
1230	*Lunch*	*Lunch*	*Lunch*
1400	Posters, Instrument Displays, and Questions and Answers	Working Group Reports, Plenary Discussion, and Recommendations for Above-Water AOPs (S. Hooker)	Guided Tour of BSI (J. Morrow and R. Booth) or Hands-On PROSIT Training (S. Hooker and J. Brown)
1410			
1420			
1430	PI Presentation (D. Dana)		
1440			
1450			
1500			
1530	*Break*	*Break*	*Break*
1600	PI Presentation (D. Antoine)	C-OPS Overview (S. Hooker)	PROSIT Above-Water AOPs Desired and Required Features (S. Hooker)
1610			
1620			
1630	PI Presentation (A. Subramaniam)	The SHALLO Instrumentation Architecture (R. Booth)	
1640			
1650	PI Presentation (J. Werdell)		
1700		Stable, Slow-Descent Profiling (J. Morrow)	
1710	PI Presentation (C. Garcia)		
1720			
1730	*Adjourn*	*Adjourn*	*Adjourn*

Fig. 1. The agenda for the 2010 AOP workshop, convened on 8–10 December in San Diego (California), showing informal meeting times (light blue), principal investigator (PI) presentations (orange), break-out sessions for working group discussions (green), posters and instrument displays (yellow), and alternative scheduling (gray blue).

Table 1. Attendees to the 2010 AOP Workshop are listed along with their affiliation, country, and e-mail address.

Investigator	*Affiliation*	*Country*	*E-mail Address*
Samir Ahmed	City College of New York	USA	ahmed@ccny.cuny.edu
David Antoine	*Laboratoire d'Oceanographie de Villefranche*	France	antoine@obs-vlfr.fr
Lore Ayoub	University of South Florida	USA	lmayoub@mail.usf.edu
Sean Bailey	FutureTech/NASA/GSFC	USA	sean.w.bailey@nasa.gov
Guislain Bécu	Université Laval	Canada	guislain.becu@gmail.com
Germar Bernhard	Biospherical Instruments Inc.	USA	germar@biospherical.com
Rocky Booth	Biospherical Instruments Inc.	USA	booth@biospherical.com
Jim Brown	CSTARS University of Miami	USA	jim.brown@miami.edu
David Court	University of California	USA	dcourt@icess.ic.ucsb.edu
David Dana	HOBI Labs	USA	dana@hobilabs.com
Mirek Darecki	Institute of Oceanology	Poland	darecki@iopan.gda.pl
Jennifer Dungan	NASA/ARC	USA	jennifer.l.dungan@nasa.gov
Robert Frouin	Scripps Institution of Oceanography	USA	rfrouin@ucsd.edu
Carlos Garcia	*Fundação Universidade do Rio Grande*	Brazil	dfsgar@furg.br
Bruce Hargreaves	Lehigh University	USA	brh0@lehigh.edu
Stanford Hooker†	NASA/GSFC	USA	stanford.b.hooker@nasa.gov
Wendy Kozlowski	Scripps Institution of Oceanography	USA	wkozlowski@ucsd.edu
Raphael Kudela	University of California Santa Cruz	USA	kudela@ucsc.edu
Randy Lind	Biospherical Instruments Inc.	USA	randyl@biospherical.com
John Morrow†	Biospherical Instruments Inc.	USA	morrow@biospherical.com
Norm Nelson	University of California Santa Barbara	USA	norm@eri.ucsb.edu
Kevin Ruddick	Royal Belgian Institute of Natural Sciences	Belgium	k.ruddick@mumm.ac.be
Brian Schieber	Scripps Institution of Oceanography	USA	bschieber@spg.ucsd.edu
Heidi Sosik	Woods Hole Oceanographic Institution	USA	hsosik@whoi.edu
Dariusz Stramski	Scripps Institution of Oceanography	USA	dstramski@ucsd.edu
Ajit Subramaniam	Lamont-Doherty Earth Observatory	USA	ajit@ldeo.columbia.edu
Sandy Thomalla	Council for Scientific and Industrial Research	S. Africa	sandy.thomalla@gmail.com
Gerardo Toro-Farmer	CMS/University of South Florida	USA	torofarm@usc.edu
Jeremy Werdell	SSAI/NASA/GSFC	USA	jeremy.werdell@nasa.gov

† Workshop organizer and co-chairman.

3. NASA instrumentation developments, both above- and in-water, which are relevant to both workshops and next-generation mission planning.

The workshop emphasized presentations on new AOP instrumentation (OSPREy and C-OPS), the desired and required features for above-water AOP data processing, working group discussions, and a community update for the in-water data processing already present in PROSIT.

The latter focus on new hardware, which is being developed by BSI, was considered a fortuitous opportunity for the community to be briefed directly by the manufacturer. For the above-water sensors, this briefing is at a critical time in the development cycle, i.e., it allows for community input regarding data processing requirements before the designs of the instruments are finalized. For the in-water instruments, the community can provide input regarding how data acquisition parameters feed directly into data processing options.

The workshop themes were established by the hardware and software components for the AOP instrumentation. The hardware theme is derived from two new sets of instruments: the in-water C-OPS and the above-water OSPREy, which are described by Morrow et al. (2010) and Hooker et al. (2011), respectively. The software theme is directly connected to PROSIT, as well as the software associated with data acquisition. The agenda was organized to provide more details about the hardware and software components:

- The development of microradiometers, which are the building blocks for the new above- and in-water instruments;
- OSPREy data acquisition and anticipated data processing capabilities;
- C-OPS data acquisition capabilities directly influence data processing capabilities;
- Existing (in-water) and anticipated (above-water) Web-based data processing capabilities, including training for the former; and
- Documentation of the Web-based processor as a living document with the protocols and algorithms that are used included in the document.

The agenda was structured to provide the newest information first to maximize the amount of time available for comments, questions, and discussion. Approximately 30 scientists from the worldwide ocean color community participated in the workshop.

2. WORKING GROUPS

The six working groups were organized as follows:

A Data ingest and data products;

B Required and desired features for optically shallow and optically deep waters;

C Contamination rejection (clouds), corrections, and data filtering;

D Sun photometry and polarimetry;

E Instrumentation networks; and

F Hyperspectral versus fixed-wavelength sensors.

The instrumentation networks working group was intended to provide more detailed information about desired and required features of autonomous sampling systems (e.g., OSPREy sites).

2.1 Working Group A

Working Group A discussed data ingest and data products for above-water sensor systems. The initial discussion concerned platforms, and it was decided that the data need not be categorized by platform (drifting, fixed, etc.) as long as the metadata are properly specified (i.e., a fixed platform simply has invariant tilt and location). It was noted that the most widely-used above-water platform is probably an aircraft. The group did not discuss aircraft-specific requirements, but again the only difference may be the values of some metadata (high velocity, varying altitude and attitude, etc.).

The discussion on the basic data format established that the American Standard Code for Information Interchange (ASCII) format is preferred and tab-delimited values are preferred, but not required. It was agreed that instrument manufacturers would provide the necessary information to translate proprietary data formats into ASCII. This could be a simple text description, documentation explaining algorithms, code fragments, or stand-alone software. Ingestion of raw data (volts or counts) is preferred, and every effort should be made to ingest data that is as raw as possible, so all processing steps can be controlled and properly executed.

The discussion on metadata centered on making sure PROSIT users are aware they must satisfy the requirements to support the current protocols (time and location, pressure tare, dark values, chlorophyll *a* concentration, sky conditions, etc.). It was also noted that certain other parameters that might enable better processing in future, e.g., filter functions and field of view (FOV), should also be identified even though they may not be used in the near future. If supplying these variables is not an impractical burden, then users should be encouraged to provide them. To make submission easier, it was agreed that metadata may be included in file headers or in separate files. The processor has a defined vocabulary for tagging data types, so flexibility is already built in.

Protocols were discussed and it was noted that some data products have multiple protocols, and only one should be recommended. The so-called *Modified Fresnel Reflectance Glint Correction* method appears to have the widest use and was recommended as the one protocol to use. The OSPREy shadowband has several options for how data are collected and processed, and it was suggested that these data can be processed like a profile.

The need for defined levels of processing and quality was discussed. The current version of PROSIT uses a coarse quality control (QC) rating, but mostly it is user oriented, because the user determines the necessary and appropriate QC criteria. It was recommended that the processor support more than just the calibration and validation perspective, but also research needs. It was acknowledged that the ocean color community does not require from everybody a data quality level that is in keeping with calibration and validation activities.

The data products were imagined to be produced by an OSPREy sensor suite—which has a separate solar reference with shadowband attachment—and included the following:

- Total radiance at the sea surface (L_T);
- Sky radiance (L_i);
- Water-leaving radiance ($L_W = L_T - \rho L_i$, where ρ is the surface reflectance);
- Polarization (Stokes parameters) of L_T and L_i with spectrograph;
- Downward global-, diffuse-, and direct irradiance; and
- Ratio of direct-to-global irradiance.

In addition, a suite of atmospheric data products are recommended, which appear in Sect. 2.4, along with the maximum diversity of QC products.

2.2 Working Group B

Working Group B discussed required and desired features for optically shallow and optically deep waters. The initial discussion attempted to come to a consensus on the definition of "optically shallow" and "optically deep." It was generally agreed that actual bathymetry, although an important variable that should be a required measurement, was not the defining parameter optically. As a working definition, optically shallow waters exist when bottom features affect the light field; optically deep waters are not affected by the bottom. Furthermore, optically deep or optically shallow waters share an obvious spectral dependence with respect to bathymetry, and the discussion did

not disclose a specific boundary separating the two. Optically shallow or deep waters were also not necessarily related to optical complexity. For the purposes of acquiring data, there was no difference in the measurement requirements for the two cases, per se.

The use of multiple wavelengths as part of more sophisticated atmospheric correction algorithms was recommended. One cited reason was the recurring failure to produce data products when the assumption in calculations of aerosol path radiance, i.e., the water-leaving radiances for the 765 and 865 nm channels are zero, is invalid (turbid waters or strong bubble field). Included in this recommendation was the use of higher spectral resolution in regions of the spectrum that are changing rapidly, especially above 1,000 nm.

In the discussion, it was observed that bubble clouds within the near-surface ocean layer can be prominent contributors to light scattering and water-leaving radiance regardless of whether the marine environment is optically shallow or deep. The time scales associated with the production and fate of bubbles within the near-surface ocean are short (on the order of a fraction of a second to minutes). The intermittent nature of bubble clouds is a significant challenge that must be taken into account in experiments designed to measure radiometric quantities near the surface and for subsequent AOP determinations. This is especially true when wind speed exceeds about $5\,\mathrm{m\,s^{-1}}$ and breaking waves inject bubbles into the water.

In addition to the issue of whitecaps, the presence of bubbles in the water column is also important within the context of atmospheric correction of ocean color measurements. The traditional black pixel assumption in the near-infrared portion of the spectrum is violated by the presence of highly scattering bubbles near the surface. The inclusion of a meteorological package, accurately recorded time, and digital camera images for detection of whitecaps and bottom features were also highly recommended. An additional requirement was added for a precise determination of the FOV (spot size) with respect to each deployment of instruments above the water.

During the discussion, it was suggested that polarization measurements should be strongly recommended. Sky radiance, L_i, is polarized, and the reflectance from the water surface depends on the polarization state of the incoming radiation. The total radiance measured at the sea surface, L_T, and the ratio of L_T/L_i, will depend on the degree of polarization of the sky. Consequently, the most accurate retrievals of L_W, require measurements of the Stokes parameters of L_i and L_T. In addition, it was pointed out that measurements of sky polarization may help in refining atmospheric correction values. The following were suggested as desirable, although not necessarily required: a) lidar for determining the concentration of colored dissolved organic matter (CDOM), b) current meter, c) bottom reflectance meter, and d) surface gravity wave sensor.

2.3 Working Group C

Working Group C discussed recommendations for the processing of above-water radiometric data and protocols, with attention to contamination rejection (clouds), correction, and data filtering. The group reaffirmed what PIs need to be able to ingest into PROSIT, which are mostly organized as time series of data with geolocation(s) for the following:

- Solar zenith angle (SZA) calculation;
- Sky radiance, $L_i(\lambda,t)$;
- Total radiance at the sea surface, $L_T(\lambda,t)$;
- Global solar irradiance, $E_d(0^+,\lambda,t)$ or an estimate from sun photometer data;
- Three-angle geometry of the sensors, including azimuth;
- Wind speed, $W(t)$; and
- Instrument metadata, e.g., calibration data, sensor FOV, and sampling frequency, integration time.

It was also noted that deployment information (photographs) is inevitably valuable and that flexibility for many systems and diverse protocols would be needed, e.g., three-sensor Trios, OSPREy, SIMBADA, SeaPRISM, etc. In return, PROSIT should provide satellite ocean color reflectances and matchup times, wind speed, cloud information, and real-time estimates of $E_d(0^+,\lambda,t)$.

Protocol issues were discussed and it was noted that there is a high diversity of protocols. The diversity is a function of the relative azimuth angle used during data collection; the sky glint correction methodology, e.g., wind speed dependence, near-infrared (NIR) correction, clear and turbid options, minimal L_T filtering, and Cox-Munk to name a few; calibration information; and instrument corrections (cosine response, stray light, etc.).

Corrections and data filtering discussions centered around being able to identify anomalous geometry, pointing errors (vertical tilts greater than 5°, relative azimuth off specification, and zenith angle off specification). Cloud flagging using the $L_i/E_d(0^+)$ ratio in the NIR (750 nm, 870 nm, or similar) should be less than 5%. The detection and avoidance of precipitation was recommended, as was ensuring clean apertures, especially on moving platforms, which are subjected to more wind-blown spray.

Longer-term ideas were discussed and included calculation of platform perturbations (which was recognized as a significant effort) and the use of a gimballed solar reference sensor.

2.4 Working Group D

Working Group D discussed sun photometry and polarimetry. The sun photometer data products included total optical depth, aerosol optical depth, Ångström parameters; aerosol single scattering albedo; aerosol size distribution; and aerosol scattering phase function. Different types

of sensor systems for the required measurements involved were discussed and included handheld-, shadowband-, and sun tracking sensors. These discussions also included fixed wavelength versus spectrograph sensors. The implications for PROSIT centered around the acknowledgment that the algorithms to calculate sun photometer data products are well established, but the atmospheric and oceanographic communities use different symbols for data inputs and data products. Another problem that was discussed was how best to derive the global solar irradiance from instruments like SeaPRISM. An unresolved question was whether or not PROSIT should be able to process a *sun photometer only* data set.

The motivation for polarimetry was improved derivation of the water-leaving radiance, $L_W = L_T - \rho L_i$, where ρ is the surface reflectance (which is a function of W); enhanced atmospheric correction; characterization of the in-water light field and scattering; and measurement of fluorescence. A principal data product was the Stokes parameters, I, Q, U, and V, which can be combined to describe the coherent radiation ($Q^2 + U^2 + V^2 = I^2$), as well as the incoherent radiation ($Q^2 + U^2 + V^2 < I^2$). The implication for PROSIT is the processor must be able to apply the Mueller matrix.

The sun photometry data products were imagined to be produced by an OSPREy sensor suite, which has a separate solar reference with shadowband attachment, and included the following:

- Polarization (Stokes parameters) of L_T and L_i with spectrograph;
- Downward global, diffuse, and direct irradiance;
- Ratio of direct-to-global irradiance;
- Direct-normal Sun irradiance (sun photometer application);
- Total optical depth, aerosol optical depth, and Ångström parameters;
- Aerosol single scattering albedo;
- Aerosol size distribution and aerosol scattering phase function;
- Total ozone column (from spectrograph);
- Precipitable water column (from spectrograph); and
- Cloud optical depth.

QC data products were also anticipated.

2.5 Working Group E

Working Group E discussed instrumentation networks with specific application to the OSPREy sensor suite. The desired characteristics in a network, acknowledging there will be different tiers of implementation, included the following: the sensors should be part of a centralized activity; at least some of the data should be accessible in real time; calibration of the sensors should be done at a single standardized instrument calibration facility; coordinated logistical support should be available; the data processing and distribution of data products should be centralized; a *pool* of instruments with a same-day swap capability should be established; and the instrumentation should be flexible, from both a scientific and technological perspective with a minimum set of criteria that should be satisfied.

The discussion of logical tiers established three types of sensor suites: a) systems with maximum redundancy and cost would be deployed at a minimum number of sites; b) more numerous fixed *validation* sites with less capability and lower cost; and c) potentially very numerous *minimal capability* sites, which might include buoys, floats, etc. Other considerations discussed in connection with the tiers were the use of portable calibration sources at a site to confirm calibration at the time of installation, as well as data availability and timeliness of QC and data processing. It was acknowledged that participants might have to *buy in* with more than one instrument to participate. Planning, in the context of NASA decadel survey missions and associated preparatory activity funding, was also discussed.

Near term recommendations to move forward included the following:

1. Populate one or two existing Aerosol Robotic Network-Ocean Color (AERONET-OC) sites with new technology (e.g., OSPREy) to provide a proof of concept, a time series continuity and instrument intercomparability, and a demonstration to overcome resistance to change (within the existing network).
2. Open a dialog across users, agencies, and network managers for the timely and efficient reporting of progress.

2.6 Working Group F

Working Group F discussed Web-based processing of hyperspectral versus fixed-wavelength above-water sensors. The group advocated the processor should make no fundamental distinction between hyperspectral and fixed wavelength sensors—hyperspectral sensors just have a lot of channels. The advantages of hyperspectral sensors are their optical bandwidth may be narrow and the band spacing is usually smaller than the actual bandwidth. The disadvantages are they may need spectral averaging, the dynamic range is almost always less, and the temporal resolution is less, both in terms of integration and data transfer times.

The higher-order data products for hyperspectral sensors might require protocols and may not be standardized. Suggested products included red-edge position (common in terrestrial applications), absorption feature depth, derivative analysis, and spectral shape transforms. For the latter, it was noted that some applications (especially airborne) use transforms that reduce the data size of spectra, but

preserve their key features (analogous to compression algorithms for photographs).

It was noted that hybrid instruments, that is instruments having both hyperspectral and discrete components (e.g., OSPREy) could be treated as separate instruments. Such an approach might possibly remove a significant advantage of such instruments, however, because the more accurate fixed wavelength channels can be used to keep the spectrograph continuously calibrated.

The role of the processor was discussed at length. The group advocated that the processor should not make research decisions. The PI is responsible for collecting meaningful data that adheres to the agreed upon sampling protocols. The processor should support—but not require—highly sophisticated users and should offer options for minimal processing. Standardization of processor functions was considered important, because it allows researchers to duplicate each other's processing on their own data sets, or try different processing on other data sets.

Specific functions that the processor should follow are as follows:

- All ingested sensor data and required metadata should be in ASCII format; optional metadata (e.g., photographs) can be in binary.
- Processing should start with the rawest data possible, preferably counts, but partially processed (e.g., dark-corrected) data should be accepted if there are no alternatives.
- The principal data product is the spectral water-leaving radiance, $L_W(\lambda)$, the global solar irradiance, $E_d(0^+,\lambda)$, plus the normalized variables created from these two observations, e.g., the remote sensing reflectance, $R_{\mathrm{rs}}(\lambda)$, the normalized water-leaving radiance, $\left[L_W(\lambda)\right]_{\mathrm{N}}$, etc.
- Output from the processing step should include a description of the configurations, corrections, and options applied in sufficient detail to unequivocally reproduce the processing that was done.
- For hyperspectral data, the output options should permit binning to a uniform wavelength spacing for intercomparison purposes.
- There should be an option to convolve the instrument data with standard satellite sensor wavelength sets, including filter response functions.
- There was a (controversial) discussion about providing derived atmospheric parameters from high-spectral-resolution data, e.g., the direct-to-diffuse ratio calculated by looking at oxygen absorption band algorithms.
- Comparison between hyperspectral and fixed wavelength instruments will require band-averaged data from the hyperspectral data to match filter wavebands, and possibly the application of corrections to the hyperspectral data based on the comparison (this is inspired by the hybrid OSPREy sensors, but could apply to other instrument designs as well).
- Data visualization can be complicated, because for hyperspectral sensors every sample is a spectrum. Sometimes it is sufficient to look at plots of specific wavebands (as is done with a filter radiometer), but sometimes a separate display is needed for looking at variations in the full spectrum.

For the latter function, harmful algal bloom (HAB) applications may require tracking the location of the red peak, which might shift slightly (selecting individual bands will not suffice for this). It was also considered desirable to be able to look at a movie or other ways of *slicing* the data. A three-dimensional perspective plot was considered appealing, but not always effective.

3. THE PROSIT MANUAL

The basic architecture for PROSIT is to correctly execute the existing protocols for processing AOP data to agreed upon data products. The utility of a set of protocols that are endorsed and maintained by a broader community far exceeds the simple accomplishment of providing the procedures for accomplishing certain tasks or measurements. As long as the protocols are a *work in progress*, periodic updates provide a timely review of the state of the art and gives new ideas or procedures a forum for evaluation. This opportunity to discuss and document how the basic tools for meeting PROSIT processing requirements are being satisfied is a critical element for maintaining the software.

Because the underlying protocols establish much of the software architecture for PROSIT, it is appealing to include the protocols in the PROSIT documentation, so there is no confusion regarding specific PROSIT features. Part of the challenge of incorporating protocols documentation is facilitating the accessibility of the information, i.e., being able to obtain and cite prior revisions, as well as the current version. There is also a strong desire to learn from prior efforts to publish protocols and make the information easy to access.

To prevent possible problems with scientists and researchers being able to access both current and legacy versions of the protocols, meetings were held with personnel at the Center for AeroSpace Information (CASI). The joint work developed a numbering and archival scheme that will be sustainable over time for a new concept in documentation for NASA—a so-called *living document*. The architecture of this approach is encyclopedic in nature, but unlike most encyclopedias, it will be added to and updated, as needed, i.e., it "lives." One of the first tasks was to determine the clearest and most efficient method for numbering and categorizing not only the initial document, but also its future updates—*without losing access to the legacy material*—a pivotal concept in scientific literature.

A living document has not been attempted in the NASA Scientific and Technical Information (STI) report series, so a number of challenges needed to be considered regarding many aspects of producing the document. Its structure, how it would be printed, subsequent updating, the report numbering scheme, and above all, the ease for researchers to access the archived data, have all been of paramount importance. Agreements were also obtained on how community members can provide material and receive co-authorship. This new document type will still be classified in the STI system as a Technical Memorandum (TM), however, which is familiar to most of the research community.

The current plan is for the PROSIT living document to include all the material needed to understand and use the software: the protocols being implemented, user manual information, important coding routines, workshop summaries, etc. Updates and revisions to the document will be done section by section as they are completed. Each section will have a unique pagination scheme for ease of updating and indexing. Sections will be distributed on three-hole punched paper, so researchers can easily replace one revision for another and store the TM in a binder if desired (Fig. 2).

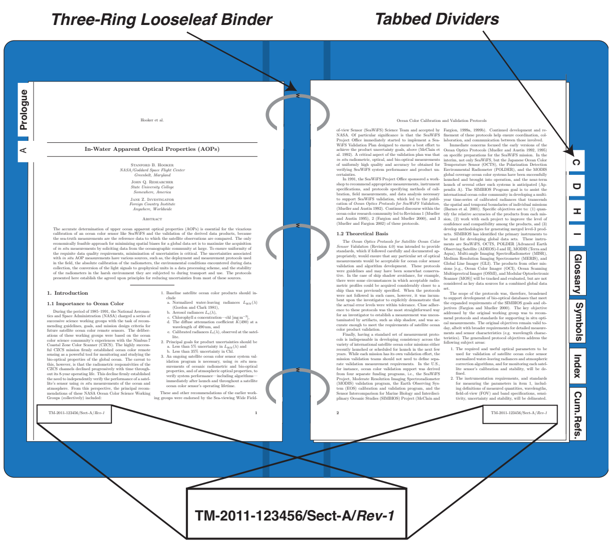

Fig. 2. A representation of a living document placed in a looseleaf binder with tabbed dividers for the glossary and symbols sections, in addition to specialized sections for a high-level index and a cumulative references section. The "magnified" footer highlights a sample CASI TM number, which will appear on each page.

4. DISCUSSION

The workshop concluded with a plenary discussion of problems and desired solutions already encountered with using PROSIT. A summary of some of the topics discussed and the ensuing recommendations to be undertaken are as follows:

1. Data ingested into PROSIT need to be processed with the objective of a unified quality, so criteria need to be established to ensure all data can be processed to the same level of completeness. This means data must be as raw as possible, metadata must be provided, and the protocols must be followed as closely as possible (because PROSIT simply follows the protocols).
2. It was recommended that PROSIT does not have to deal with significant errors made during data acquisition, but does need to be able to flag such data, which might only be possible if the PI identifies the problem. The latter assumes the PI knows about the problem, which might not always be the case. For example, some PIs used irradiance sensors with a responsivity that was only valid in water as above-water solar references.
3. Given limited resources, there are only two options with compromised data quality: either work on the individual data sets to improve them, or work on better programming routines to trap and flag bad data. The group consensus was the latter option is the best. It should be the PI's responsibility to correct compromised data or investigate how the data can be used for other objectives.
4. Some problems during acquisition can be solved with better PROSIT tools. For example, some PI's do not apply a pressure tare, but the data acquisition might include data when the profiler was on the deck of the ship before or after the cast(s). The PROSIT `Cast Editor` page should be modified to identify not only data rejection intervals (e.g., data collected after the bottom of a cast), but also to identify data to be used for the pressure tare or dark counts.
5. The automated submission of data and products to the SeaWiFS Bio-Optical Archive and Storage System (SeaBASS) is a required feature, but should include processing headers that explicitly identify missing criteria, configuration parameters, and quality flags.
6. If all the established criteria are met for a particular data ingestion, then the original data and metadata plus the resulting data products could be stored in SeaBASS, otherwise the data would be for the PI's research purposes and not distributed.
7. The SeaBASS discussion ultimately resulted in a recommendation to establish a submission (data quality) threshold. If an ingested data set satisfies the threshold, the data are accepted for full processing and submitted to SeaBASS; if not, the data can be processed, but the problems preventing acceptance will likely not be mitigated and poorer quality results will be obtained.

8. The SeaBASS threshold was seen as a way to release PROSIT from the unbounded burden of trying to create submission quality data, but does not prevent anyone from using PROSIT. The threshold was also seen as a motivator to improve data quality over time.
9. The nascent training module in PROSIT is important and should be expanded. Training should be used to show how to process data, as well as what is required to collect data for correct processing. A field *checklist* in the living document would be beneficial to novice practitioners.
10. A discussion on the above-water analogs to the above in-water topics included similar recommendations. A separate recommendation, however, was to adopt only one above-water method for PROSIT to implement, and the consensus was to use the Modified Fresnel Reflectance Glint Correction method, because it is used the most. If another protocol is proved superior, then PROSIT will evolve and change to that protocol.
11. A discussion on whether or not alternative protocols will be considered inferior to the PROSIT protocol established the need for performance metrics, so alternatives can be evaluated objectively and the state of the art can be advanced quantitatively.
12. Shadowband, sun photometry, and polarimetry processing were discussed within the context of porting whatever the OSPREy activity accomplishes into PROSIT.
13. A future workshop, approximately in late 2011 or early 2012, is recommended to discuss a) the above-water capabilities implemented in PROSIT, b) refinement of the in-water capabilities, c) drafting of performance metrics for both above- and in-water processing, and d) revision of the protocols involved (e.g., self-shading correction).
14. A discussion on making point measurements close to the sea surface emphasized the difficulty of doing that using an extrapolation interval and led to discussions on alternatives, for example, using measurements of the inherent optical properties (IOPs), and how to evaluate and include them. The uncertainty part of the discussion included calibration uncertainties and how this problem also applies to the alternatives. The recommendation was to keep an open mind.
15. How best to improve early participation of PIs and new practitioners with PROSIT established that the burden of working with problematic data falls on the PI and the community in general. A substantial advantage will be PIs can sensibly compare results for the first time.

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Glossary

ACE Aerosol-Cloud-Ecosystems
AERONET Aerosol Robotic Network
AOP Apparent Optical Property
ASCII American Standard Code for Information Interchange

BSI Biospherical Instruments Inc.

CASI Center for AeroSpace Information (NASA)
CDOM Colored Dissolved Organic Matter
C-OPS Compact-Optical Profiling System
COTS Commercial Off-The-Shelf
CSTARS Center for Southeast Tropical Advanced Remote Sensing

FOV Field of View

GSFC Goddard Space Flight Center

HAB Harmful Algal Bloom
HOBI Hydro-Optics, Biology, and Instrumentation

IOP Inherent Optical Property

NASA National Aeronautics and Space Administration
NIR Near-Infrared

OC Ocean Color
OSPREy Optical Sensors for Planetary Radiant Energy

PACE Pre-Aerosol, Clouds, and Ocean Ecosystem
PI Principal Investigator
PROSIT Processing of Radiometric Observations of Seawater using Information Technologies

QC Quality Control

SeaBASS SeaWiFS Bio-Optical Archive and Storage System
SeaPRISM SeaWiFS Photometer Revision for Incident Surface Measurement
SeaWiFS Sea-viewing Wide Field-of-view Sensor
SIMBADA Satellite Validation for Marine Biology and Aerosol Determination, Advanced
SSAI Science Systems and Applications, Inc.
STI Scientific and Technical Information
SZA Solar Zenith Angle

TM Technical Memorandum

Symbols

$E_d(0^+,\lambda,t)$ The global solar irradiance, or an estimate from sun photometer data.

I One of the Stokes parameters.

$L_i(\lambda,t)$ The sky radiance.
$L_T(\lambda,t)$ The total radiance at the sea surface.
$L_W(\lambda)$ The water-leaving radiance (defined as $L_T - \rho L_i$).
$[L_W(\lambda)]_{\mathrm{N}}$ The normalized water-leaving radiance.

Q One of the Stokes parameters.
$R_{rs}(\lambda)$ The remote sensing reflectance.
U One of the Stokes parameters.
V One of the Stokes parameters.
$W(t)$ The wind speed.
λ Wavelength.
ρ The surface reflectance.

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14. ABSTRACT
The rationale behind the current workshop, which was hosted by Biospherical Instruments Inc. (BSI), was to update the community and get community input with respect to the following: topics not addressed during the first workshop, specifically the processing of above-water apparent optical property (AOP data) within the Processing of Radiometric Observations of Seawater using Information Technologies (PROSIT) architecture; PROSIT data processing issues that have developed or tasks that have been completed, since the first workshop; and NASA instrumentation developments, both above- and in-water, that are relevant to both workshops and next generation mission planning. The workshop emphasized presentations on new AOP instrumentation, desired and required features for processing above-water measurements of the AOPs of seawater, working group discussions, and a community update for the in-water data processing already present in PROSIT. The six working groups were organized as follows: a) data ingest and data products; b) required and desired features for optically shallow and optically deep waters; c) contamination rejection (clouds), corrections, and data filltering; d) sun photometry and polarimetry; e) instrumentation networks; and f) hyperspectral versus fixed-wavelength sensors. The instrumentation networks working group was intended to provide more detailed information about desired and required features of autonomous sampling systems. Plenary discussions produced a number of recommendations for evolving and documenting PROSIT.

15. SUBJECT TERMS
SeaWiFS, apparent optical properties, AOP, optically complex waters, PROSIT

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